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Assessment of wind energy to power solar brackish water greenhouse desalination units: A case study from Algeria

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ABSTRACT

The Algerian desert dominates large parts of the country's vast territory, and Algeria is among the countries filling most of the world's largest desert. In fact the country is over 80% desert. Even though more than 80% of the population is located in the northern Mediterranean coastal zone, most of oil and gas fields are located in the country's vast southern desert called Sahara. Furthermore, the desert region is developed into a major tourist destination. This arid zone region is characterized by a lack of potable water. However, in addition to the abundant solar energy, the region is also endowed with important wind and brackish groundwater resources with different qualities. Therefore, a brackish water greenhouse desalination unit that is powered by wind energy is a good solution for desalting groundwater for irrigation purposes in this region. Brackish water can be used to cool the greenhouse, creating the proper climate to grow valuable crops. Moreover, at the same time the fresh water that is produced in this system may be sufficient for the irrigation of crops grown inside the unit. In this study, five typical regions in the Sahara were selected and investigated. These regions were selected since they were areas of traditional agriculture. The frequency distributions of wind speed data were collected from Surface Meteorology and Solar Energy (SSE) statistics developed by NASA and evaluated for a 10-year period. The distributions were used to determine the average wind speed and the available wind power for the five locations. The results indicated that the available wind energy is a suitable resource for power production and can be used to provide the required electricity for the brackish groundwater greenhouse desalination units.

Contents

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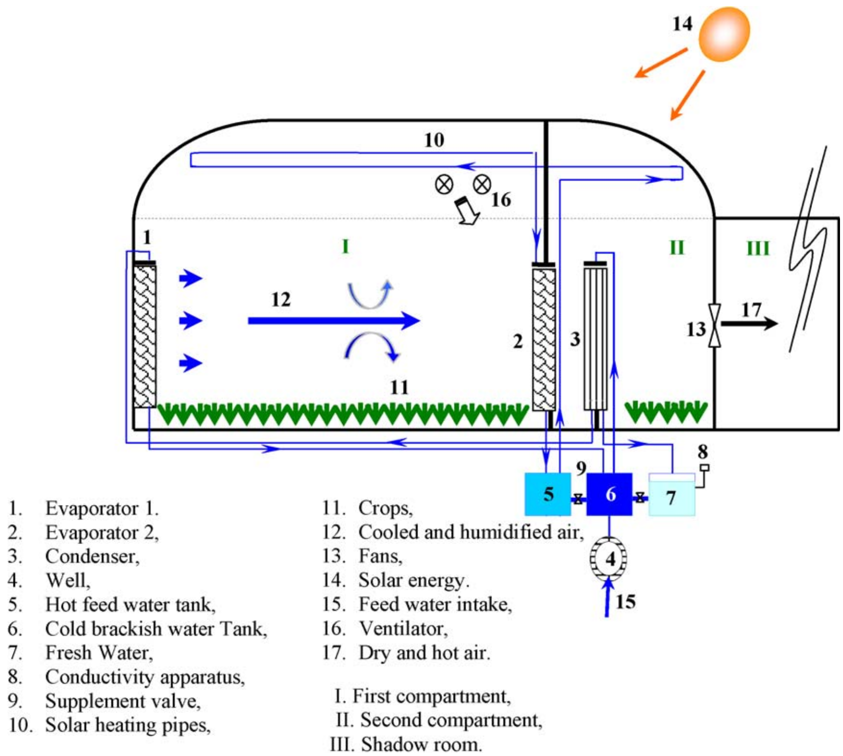

Fig. 1. Process' schematic [3].

1. Introduction

The coupling of wind/solar energy and desalination systems holds great promise for increasing water supplies in water scarce regions [1]. An effective integration of these technologies will allow countries to address water shortage problems with a domestic energy source that does not produce air pollution or contribute to the global problem of climate change. Meanwhile the costs of desalination and renewable energy systems are steadily decreasing, while fuel prices are rising and fuel supplies are decreasing. The desalination units powered by renewable energy systems are uniquely suited to provide water and electricity in remote areas where water and electricity infrastructures are currently lacking. The study of the potential interface between desalination and renewable energy technologies has increased significantly in the last 5 years. Considering that the energy requirements for desalination continues to be a highly influential factor in system costs, the integration of renewable energy systems with desalination seems to be a natural and strategic coupling of technologies [2].

Solar distillation is a process in which the energy of the sun is used directly to evaporate fresh water from sea or brackish water. The process has been used for many years, usually for small-scale applications. Solar desalination systems have been well detailed by Refs. [3–7]. The first known solar distillation unit, a simple still, was constructed in Chile by Charles Wilson in 1872 [8].

The humidification–dehumidification process (HD) is an attractive technique that can be adapted for water desalination when the demand is decentralized. This method presents several advantages such as suppleness in capacity, modest installation and operating costs, simplicity, possibility of using low temperature and the use of renewable energy (solar, geothermal, recovered energy or cogeneration) [4,9,10].

A more recent example of a humidification–dehumidification system is a pilot plant built at Kuwait University [11]. An air-dehumidification method suitable for coastal regions was also described by Khalid [12].

Paton and Davies [9] proposed a Seawater Greenhouse system utilizing a humidification–dehumidification process (Fig. 1). Their seawater greenhouse produced fresh water and crop cultivation in one unit. It also offered a sustainable solution to the problem of providing water for agriculture in arid coastal regions. The greenhouse acted as a solar still while providing a controlled environment suited for the cultivation of crops.

Many parts of the world are experiencing a chronic shortage of water, especially those of the Middle East and North Africa region. In these countries more than 80% of all fresh water consumed is used for agricultural purpose [9]. As fresh water resources are limited, there is an immense pressure to decrease agricultural use of water. The seawater greenhouse provides a good solution to the problem by creating a growing environment that substantially reduces the amount of water required for irrigation, together with a new source of fresh water [4].

2. Process description

The seawater/brackish water greenhouse uses sunlight, seawater or brackish water and the atmosphere to produce fresh water and cool air, creating temperature conditions for the cultivation of crops. The process recreates a natural hydrological cycle within a controlled environment. Feed water is pumped from a well. The natural sand acts as a filter and keeps out solid particles and other impurities. Filtered water is sent to the cold tank where it is fed to the condenser and then to the first evaporator. The brine water from the first evaporator turns over to the cold tank (Fig. 1). The evaporator is the entire front wall of the greenhouse structure. It consists of a cardboard honeycomb lattice and faces the prevailing wind. Feed water trickles down over this lattice, cooling and humidifying the air passing through into the planting area. Dust, salt spray, pollen and insects are also trapped and filtered out. Fans draw the air through the

greenhouse and into the shade room. Air passes through a second brackish water evaporator and is further humidified to saturation point. Only a small fraction of sunlight is useful for photosynthesis. Sunlight is selectively filtered by the roof elements to remove radiation that does not contribute to photosynthesis. This helps to keep the greenhouse cool while allowing the crops to grow in high light conditions. In a normal greenhouse the remaining sunlight translates into hot growing conditions and large watering requirements. The current greenhouse was equipped by a recovery system which consists of long pipes placed all with length of the greenhouse. The brackish water in the pipes was heated directly by sunlight's radiations and feed the second evaporator before returning to the hot tank. Air leaving the evaporator is nearly saturated and passes over the condenser coils carrying cool ground water, which may come from the cold tank. The fresh water condensing from the humid air is piped to storage for irrigation. The water vapour leaving Evaporator 2 may have some salt droplets in it, which could end up in the fresh water. However, even if this occurs the water should still be potable.

3. Geophysical description of the case study country

Algeria has an area of 2,381,741 km^2 and a population of about 33 millions. It is the Africa's second-largest country and the eleventh in the word in term of land area. The country is divided into four main physical regions. The first region located in the north is the Mediterranean coastline of 1200 km in length, where most of the country's population (80%) and industry are concentrated. The second region is the Tell which extends 80–190 km inland from the coast. The next region, lying to the south and southwest is the High Plateau; a highland region of level ground together with the mountains and massifs of the Saharan Atlas of the south region. The fourth region, comprising more than 80% of the country's total area, is the great expanse of the Algerian Sahara [1].

4. Agriculture potential and policy in the case study region

Agricultural production is a moderate contributor to the Algerian economy. The lack of investment, insufficient water resources, and dependence on rainwater for irrigation has contributed to the decrease of agriculture production yield. The production of cereals as well as orchard and industrial crops has significantly dropped. As a result, the country has become so dependent on food imports, accounting more than 75% of food needs [13].

Although the case study country is the second-largest country in Africa, the arable land of about 8.2 million ha accounts for only 3.4% of the total land area [13]. The bulk of Algeria's crops are cultivated in the fertile but narrow plains around Bejaïa and Annaba in the east, in the Mitidja Plain south of Algiers (The capital), and from Oran to Tlemcen in the west. The agricultural sector's dependence on rainwater for irrigation has often affected its production levels, especially during droughts.

The country's main crops are cereals, citrus fruit, vegetables, and grapes. Fresh date exports have risen sharply in the last years and have become the second-largest export after hydrocarbons. Some 72,000 ha are cultivated with palm trees, mainly in the Saharan oases. The vast Sahara desert, which spans much of the south central part of the country, is not available for agriculture due to the leak of irrigation water and the high investments costs. Hence, despite government efforts to extend funding and technical assistance to southern farmers there is still a need to increase the productivity of the agricultural sector.

5. Wind data

The wind data used in this paper were obtained from the Algerian Metrological Office (ONM) [14] and from the NASA Surface Meteorology and Solar Energy (SSE) Data [15]. The SSE data set is derived mainly from several other data sets developed by NASA, including the Goddard Earth Observing Systems Version 1 (GEOS-1), using an atmospheric model constrained to satellite and sounding observations. These data sets, in turn, were derived from the analysis of observations made by earth-orbiting satellites: the Geostationary Operational Environmental Satellites (GOES) and Polar-Orbiting Environmental Satellites (POES) from the US National Oceanic & Atmospheric Administration (NOAA), the Meteorological Satellites (Meteosat) operated by the European Space Agency, and the Geostationary Meteorological Satellites (GMS) operated by the Japan Meteorological Agency. The SSE is a valuable resource since it is the lone resource for isolated and remote locations in Algeria. The NASA SSE data set is formulated from data gathered for the 10-year period from July 1983 to June 1993 [16].

6. Yearly mean wind speed and sites description

The latitude, longitude, altitude and topographic situation of the selected sites are summarized in Table 1 [15]. The seasonal variation of wind speed provides information about the availability of wind speed during different months of the year.

The statistics collected from the SSE Database [15] (Fig. 2) provides the variation of monthly average wind speed of the main selected locations during the entire data collection period. According to Fig. 3a, one can see that the eastern coastal localities are characterized by a good wind potential compared to the western coastal district. The wind speed increases in the east-west direction. Fig. 2b illustrates the wind distribution of the districts located in the north of the Atlas Tellien. It represents practically the same behavior with the maximum values recorded in the spring season. Localities situated in the highlands have greater mean wind speed reaching their maximum during the spring season. Fig. 2b and c represents the evolutions of the main Sahara areas. The monthly mean wind speed is considerably high and attains its highest values during the spring season [17].

Table 1
Geographical data of the selected sites [15].

Sites	Longitude	Latitude	Altitude (m)	Topographic situation
Bejaia	36.7N	5.1E	2.0	Coastal zone
Skikda	36.9N	7.0E	7.0	Coastal zone
Oran	35.6N	−0.6E	90.0	Coastal zone
Constantine	36.3N	6.6E	694.0	North of Tellien mountains
Mascara	35.6N	0.3E	474.0	North of Tellien mountains
Tebessa	35.5N	8.1E	813.0	North of Tellien mountains
Tlemcen	35.0N	−1.5E	247.0	North of Tellien mountains
Tiaret	35.3N	1.4E	1127	Highlands
Setif	36.2N	5.4E	1038.0	Highlands
Djelfa	34.7N	3.3E	788.0	Highlands
El Bayadh	33.7N	1.0E	1341.0	Highlands
Adrar	27.9N	−0.3E	263	Sahara
Biskra	34.8N	5.7E	87	Sahara
In Salah	27.2N	2.5E	293	Sahara
Tindouf	27.7N	8.2E	566	Sahara
Bechar	31.6N	−2.2E	773	Sahara
Ghardaia	32.4N	3.8E	450	Sahara
In Amenas	28.1N	9.6E	562	Sahara
El Golea	30.6N	2.9E	397	Sahara
Hassi Messaoud	31.7N	6.2E	142.0	Sahara
Ain Safra	32.8N	−0.6E	967.0	Sahara
El Oued	33.5N	6.1E	63.0	Sahara

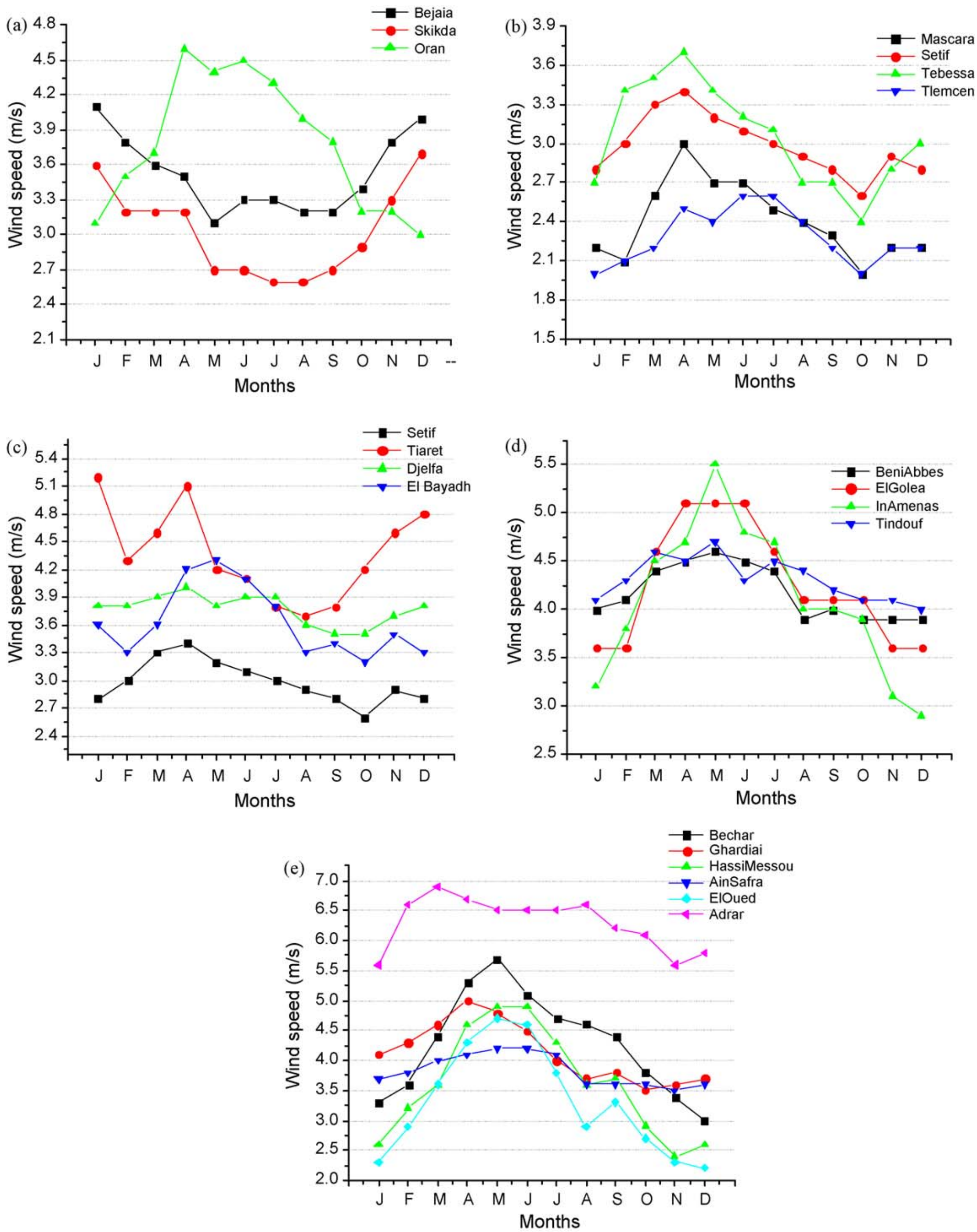

Fig. 2. Monthly average wind speed of the main selected locations [15].

The analysis of the different wind velocity distributions demonstrate that the Algerian Sahara represents an important wind power reserve compared to the other three physical regions. It is also evident, that the site of Adrar, compared to the other sites has the highest wind speed. The above analysis allowed us to select the best five regions of Algeria where wind is the most significant. These regions are centered around the towns of Adrar, Tindouf, Ghardaia, Amenas and Bechar, all situated in the south of the country. These regions are also characterized by important brackish water reserves [18] which may be used for traditional agriculture.

According to a recent review by Himri et al. [19] on the sites of Adrar, Timimoun and Tindouf, it was found that the maximum wind speed occurred at 9 am at all the locations while the minimum at 9 pm. In general, higher winds were observed between 9 am and 6 pm while they were lower during the rest of the day. This indicates that higher electricity could be produced during 9 am and 6 pm. In a similar study on a solar Seawater Greenhouse, Mahmoudi et al. [3] concluded that in only 8 h (i.e. between 9 am and 5 pm), the desalination unit produced 98% of total fresh water. This time interval was in the same range as that of Himri et al. [19] and corresponds to the duration where wind speed was the highest. In addition, Youcef Ettoumi et al. [20] presented an assessment of a wind power potential for five locations in Algeria. He found that the wind turbines can easily satisfy the electricity need in irrigation and its household applications in rustic and arid regions.

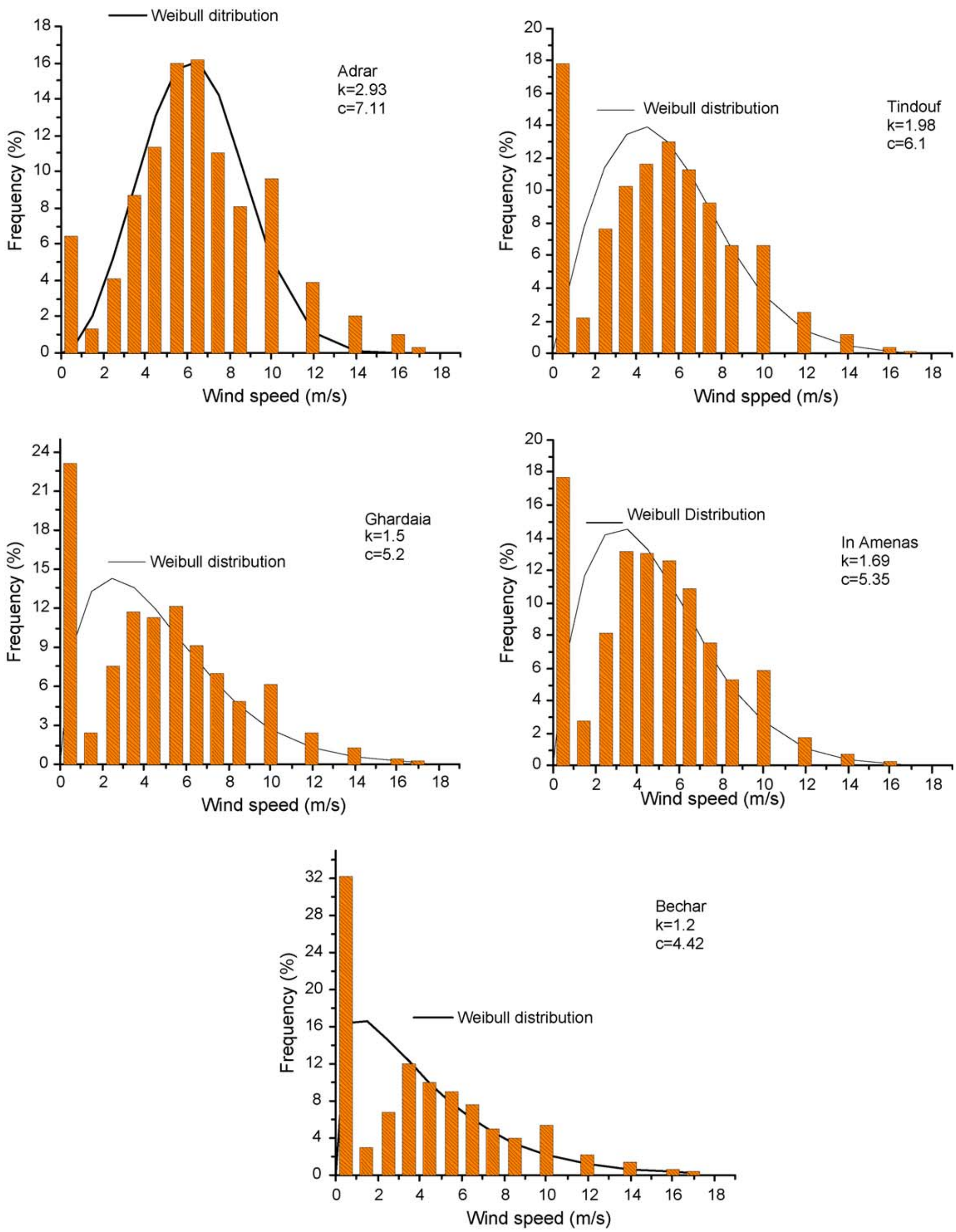

Fig. 3. Wind speed frequency with fitted Weibull distribution of the selected sites [14].

It can be concluded that wind energy conversion systems (WECS) represent a viable alternative energy source for agriculture in the case study region. In particular, these systems can advantageously be coupled with desalination units such as the Seawater Greenhouse which can be installed in remote locations with access to brackish or sea water.

7. Wind speed frequency distribution

According to the Data collected from the Algerian Metrological Office (ONM) [14], the statistical analysis of wind speed was done using the hybrid Weibull distribution. Both the estimated wind speed frequencies obtained using the distribution and the Weibull distribution parameters k and c of the selected sites are shown in Fig. 3. The intervals that were considered varied from 0 to 18 m/s.

More interesting wind energy potential is located in the southern part of Algeria. The Saharian sites of Adrar, Tindouf, Ghardaia, In-Amenas and Bechar have frequencies of the order of 83.3%, 72.6%, 66.8%, 71.4% and 58% respectively, for speeds greater than or equal to 3 m/s cut-in wind speed, which contributes to the generation of electricity from wind. Table 2 gives a summary of wind speed frequency distributions in terms of percentages for the selected sites in the southern part of the case study area (Diaf et al. [21]). It can be seen that the site of Adrar has the highest wind

Table 2
Wind speed distribution, Wind speed duration D (h) and power density P (W/m^2) at different speeds interval at 10 m above the ground for the five selected sites [21].

Velocity (m/s)	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–11	11–13	13–15	15–17	>17	Total
Adrar															
Wind velocity frequence (%)	6.4	1.3	4.1	8.7	11.3	16.0	16.1	11.0	8.1	9.6	3.9	2.0	1.0	0.3	
Duration (h)	560.64	113.88	359.16	762.12	989.88	1401.6	1410.3	963.6	709.56	840.96	341.64	175.2	87.6	26.28	8742.4
Power (W/m^2)	0.0048	0.0267	0.3907	2.2753	6.2812	16.238	26.970	28.307	30.343	58.56	41.109	33.476	24.985	8.9907	277.96
Bechar															
Wind velocity frequence (%)	32.2	3.1	6.7	12.1	10.0	9.0	7.6	5.1	4.1	5.4	2.3	1.4	0.6	0.4	
Duration (h)	2820.7	271.56	586.92	1059.9	876	788.4	665.8	446.8	359.2	473	201.5	122.6	52.6	35	8760
Power (W/m^2)	0.025	0.064	0.641	3.178	5.581	9.171	12.784	13.178	15.422	33.075	24.343	23.53	15.053	13.13	167.39
Ghardaia															
Wind velocity frequence (%)	23.1	2.4	7.6	11.7	11.3	12.1	9.1	7.0	4.9	6.1	2.5	1.3	0.5	0.3	
Duration (h)	2025.6	210.5	666.4	1025.9	990.9	1061	798	613.8	429.7	534.9	219.2	114	43.8	26.3	8751.2
Power (W/m^2)	0.018	0.05	0.728	3.075	6.313	12.341	15.324	18.114	18.431	37.424	26.46	21.849	12.544	9.848	180.83
In amenas															
Wind velocity frequence (%)	17.7	2.8	8.1	13.2	13	12.6	10.9	7.6	5.3	5.9	1.8	0.7	0.3	0.1	
Duration (h)	1550.5	245.3	709.6	1156.3	1138.8	1103.8	945.8	665.8	464.3	516.8	157.7	61.3	26.3	8.8	8760
Power (W/m^2)	0.012	0.035	0.712	3.183	6.664	11.792	16.838	18.035	18.309	33.188	17.496	10.805	6.912	3.05	159.15
Tindouf															
Wind velocity frequence (%)	17.8	2.2	7.6	10.3	11.6	13	11.3	9.2	6.6	6.6	2.5	1.1	0.3	0.1	
Duration (h)	1556.2	192.3	664.4	900.5	1014.1	1136.5	987.9	804.3	577	577	218.6	96.2	26.2	8.7	8777.5
Power (W/m^2)	0.014	0.045	0.725	2.7	6.463	13.217	18.974	23.721	24.788	40.364	26.354	18.488	7.526	3.283	185.96

energy potential. The location of Tindouf ranks second, followed by Ghardaia, Bechar and In-Amenas respectively. Our resluts and those of Diaf et al. [21] were similar with the exception being the cases of Bechar and In-Amenas.

The analysis of Weibull parameters shows that the shape parameter k varies between 1.2 and 2.93 while the scale parameter c varies between 4.42 and 7.11. The highest values of k and A were found in Adrar, located in the southwest part of the country. Whereas the lowest values of the two parameters were found in Bechar.

In Fig. 3 are shown histograms of the wind speed observations at the five selected sites with fitted Weibull frequency functions. As shown in Fig. 3, the Weibull distribution fits the observed distribution reasonably well in the relevant wind speed range. An exception is made for the sites with high frequencies for low wind speed. This distribution shows that the higher average wind speeds generally corresponds to the higher values of k. Small values of k imply that the data tend to be distributed over a relatively wide range of wind speeds.

8. Concluding remarks

Much research has been directed at addressing the challenges in using renewable energy to meet the power needs for desalination plants. Wind energy and solar energy are clean and renewable fuel sources. This study has analyzed the feasibility of using wind energy to power brackish water greenhouse desalination units proposed for the development of the southern region of the case study country of Algeria. It was noted that in only 8 h (i.e. between 9 am and 5 pm), the greenhouse produces 98% of the total freshwater. This interval corresponds to the highest wind efficiency interval.

The Brackish water greenhouse will use the wind energy produced mainly to power electrical equipments such as pumps, ventilators and fans. The left over electrical power could, for example, be used for cooling the storage rooms of the produced food and also to produce cooling water for the Brackish water greenhouse condenser.

In closing, analysis shows that there is great potential for the use of wind energy in five locations in the southern part of the case study country of Algeria. Wind power could provide a viable source of energy to power the brackish water greenhouse desalination units which can help in the development of the region.

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